Extracting the equation of state from a microscopic non-equilibrium model

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One of the main goals of relativistic heavy ion collisions is the determination of the nuclear equation of state. At high energies, semiclassical cascade models in terms of scattering hadrons have proven to be rather accurate in explaining experimental data. Therefore it is of fundamental interest to extract the equation of state from such a microscopic model, i. e. to investigate the equilibrium limits and bulk properties, which are not an explicit input to the non-equilibrium transport approach with its complicated collision term (unlike e. g. in hydrodynamics). In Fig. 1 we study the thermodynamic properties of infinite nuclear matter with the Ultrarelativistic Quantum Molecular Dynamics 1.0β (URQMD), a semiclassical transport model[1]. The model is based on classical propagation of hadrons and stochastic scattering (s channel excitation of baryonic and mesonic resonances/strings, t channel excitation, deexcitation and decay). For this study the potentials have been switched off. To simulate infinite hadronic systems we construct a box of volume 250 fm^3 with periodic boundary conditions, and initialize 40 nucleons — that is

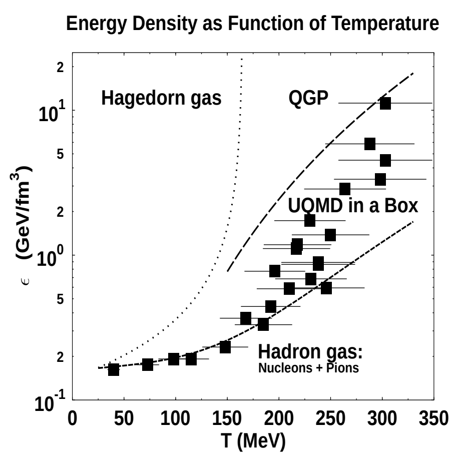

Figure 1: 'Equation of state' of infinite nuclear matter, calculated with URQMD (preliminary). Shown is the energy density as a function of temperature (extracted with a least square fit to the baryon momentum spectrum) at fixed net-baryon density of $\rho = 0.16$ fm^{-3}. The equations of state of a Hagedorn-gas, of a quark-gluon plasma, and of an ideal gas of nucleons and ultrarelativistic pions are also depicted.

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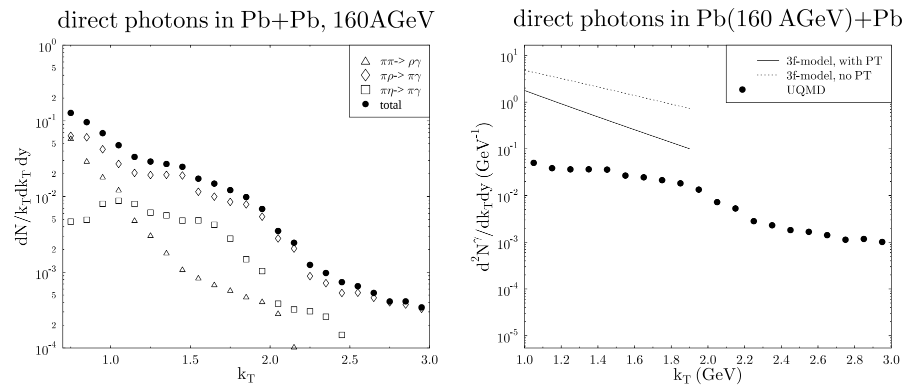

Figure 2: Transverse momentum spectrum of directly produced photons in Pb+Pb collisions at 160 GeV/u calculated with URQMD (left). The contributions of the different processes are shown. The resulting spectrum is compared with hydrodynamical calculations (right). For the photon source, an equation of state with and without a phase transition is assumed.

ground-state nuclear density — randomly in phase space, varying the total energy density. After the system has equilibrated according to the URQMD simulation, the temperature is extracted by fitting the particles' momentum spectra. Alternatively, the temperature can be extracted from the relative abundances of different hadrons, e. g. the Δ/N ratio, which should yield the same temperature. This has been checked in the current simulation. The result of this procedure is plotted in Fig. 1. It appears that the energy density rises faster than T^4 at high temperatures of $T \approx 200 - 300$ MeV. This indicates an increase in the number of degrees of freedom. It may be interpreted as a consequence of the numerous high mass resonances and string excitations, which in a way release constituent quark degrees of freedom (but, of course, no free current quarks as in an ideal QGP). Investigations of equilibration times and relative particle and cluster abundances are in progress. Moreover, the admittedly poor statistics have to be improved.

Experimentally, one can access the equation of state of strongly interacting matter by measuring thermal electromagnetic radiation emitted in heavy ion collisions. We have calculated direct photon production in Pb+Pb collisions at 160 GeV/u within the framework of URQMD 1.0 β. To improve statistics, the total meson-meson cross sections were fixed to 15 mb (independent of

$\sqrt{s}$). For the sake of comparison with earlier hydrodynamical calculations (see [2] and refs. therein) we considered only the processes $\pi\rho \rightarrow \pi\gamma$, $\pi\eta \rightarrow \pi\gamma$ and $\pi\pi \rightarrow \rho\gamma$. The amplitudes are taken from [3]. As can be seen in Fig. 2 (left) the $\pi + \rho \rightarrow \pi + \gamma$ process dominates the spectrum in the transverse momentum range considered. Fig. 2 (right) shows that the direct photon slope from the microscopic calculation equals that from the hydrodynamical calculation without a phase transition in the equation of state of the photon source. In the case of a phase transition the slope becomes significantly steeper due to a lower temperature at given energy density. The lower absolute yields of the direct photons from the URQMD may indicate that the meson abundance at early times is smaller than in the hydrodynamical model of [2], although the final yields are similar (due to higher mass mesons and baryon resonances). Thermal and in particular chemical equilibrium may not be established within URQMD in the early stage of the collision (where the large transverse momentum photons are produced). In contrast, in the hydrodynamical calculation local thermal and chemical equilibrium of the produced particles is assumed from the very beginning. Experimental studies on direct photons, under way at CERN [4], will help to settle these questions in the near future.

Acknowledgments

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